Coherent Soft X-ray Magnetic Scattering

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INTRODUCTION

The invention of the laser in the 1960's revolutionized many areas of physics, chemistry and biology. The coherence of these spectacular new sources enabled both new science and new technology. Two of the advances due to the laser were the development of dynamic light scattering and of speckle metrology. The undulator sources at third-generation synchrotron sources provide dramatic increases in the coherence of x-ray sources. Recently, the first dynamic x-ray scattering experiments [1, 2, 3] and the first x-ray speckle metrology experiments [4, 5] have been done. The smallest length scales that can be studied with these techniques are set by the wavelength of the coherent light. The motivation for using coherent x-ray sources is to extend the spatial resolution from optical length scales to the molecular and atomic length scales. Here, we describe how coherent soft-x-ray magnetic scattering can be used to study the magnetic order down to molecular length scales in the new thin-film magnetic materials that are now under intense study because of their applications in the next generation of magnetic storage devices. We report soft x-ray speckle metrology experiments on Co:Pt films at a wavelength near the Co L-edge where pronounced magneto-optical effects provide marked scattering contrast. Our results can be used to test the hypothesis of microscopic return point memory.

MATERIALS AND EXPERIMENTAL POCEDURES

Our sample was grown by magnetron sputtering onto a smooth, low-stress, 160-nm-thick SiN_x membrane. The substrate was heated to 250^{o} C and the sample consists of a 20-nm-thick Pt buffer layer, 50 repeating units of a 4-Å cobalt and 7-Å Pt layers, and a 3-nm-thick Pt cap which prevents oxidation. The broken symmetry at the Co-Pt interface provides the anisotropy that tends to align the magnetization normal to the interfaces as first predicted by Néel. The magnetic domain structure of our sample was measured at zero applied field using magnetic x-ray microscopy (MXM) at the ALS or magnetic force microscopy. The domain structure is driven by the competition between the perpendicular interfacial anisotropy and thin-film shape anisotropy resulting in 'worm-like' domains with a characteristic width of 2000Å. The sample was mounted on a rotation stage in our vacuum chamber inside an electromagnet that could apply magnetic fields up to 1.1T perpendicular to the surface of our sample and, hence, parallel or antiparallel to the local magnetization. The diffuse magnetic scattering was detected with a soft x-ray CCD detector using spatially filtered undulator light on beamline 9.0.1. A beam stop was used to prevent the incident x-ray beam from damaging the detector.

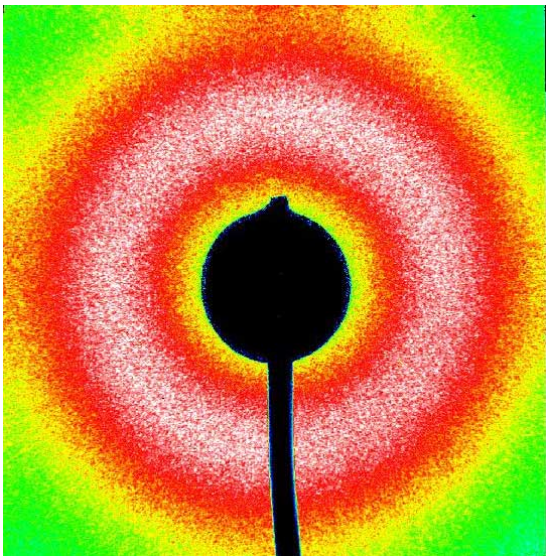

Figure 1: Measured magnetic speckle pattern for our sample at zero applied field. This image shows that the shape of the magnetic speckle pattern is annular at zero field. The shadow of the beam stop is clearly visible in the center of this image, as is the support wire for the beam stop.

EXPERIMENTAL RESULTS

Figure 1 shows the soft x-ray magnetic speckle pattern of our Co:Pt multilayer measured on beamline 9.0.1 at the ALS. The measured magnetic speckle pattern near zero field is a broad annulus. Because this scattering pattern occurs at small scattering angles, the images from the CCD are essentially linear in reciprocal space. At zero field, the radius of the annulus corresponds to an average width of the magnetic domains of ~2000 Å, and the radial width corresponds to a correlation length of ~4000 Å. Such a ratio, where the correlation length is twice as big as the near-neighbor spacing, is very common in simple liquids where the correlations often only extend out to the first-neighbors.

We have measured the evolution of the speckle pattern as a function of applied field. Near saturation magnetization, the annular scattering pattern disappears in favor of a pattern with monotonically decreasing intensity as a function of scattering wave vector. Such behavior is characteristic of a system lacking even short-range order. These two kinds of pattern coexist over a range of applied field, implying a transition between a 'liquid-like' and a 'gas-like' phase for the magnetic domains as the field is varied. These terms refer to the kind of order in the nominally static magnetic domains and are not meant to imply the phases are fluctuating in time.

The strength of condensed phase scattering techniques is that they provide a statistical average over a macroscopic amount of material. The above conclusions about 'liquid-like' and 'gas-like' behaviors, for example, are derived from a simple analysis of the envelope of scattered intensity. All that is required to draw such a conclusion is that the transverse coherence length of the incident beam be long compared to the characteristic ordering length in the sample - the domain size and the degree of short-range order, in the present case. By using a transversely coherent beam - one where the transverse coherence length is comparable to the beam diameter itself - much more information can be derived. Specifically, the speckle pattern in Figure 1 is the diffraction pattern of the magnetic domain structure. By comparing two related speckle patterns, we can deduce the degree of similarity of the microscopic domain structures.

We have initiated such measurements to test the degree of microscopic return point memory in this system. This terminology refers the degree to which the domain structure is reproduced in

traversing major and minor magnetization loops. We find that taking the sample around the major magnetization loop, which by definition implies macroscopic return point memory, erases memory of the microscopic domain pattern completely. We have measured the gradual loss of microscopic return point memory for minor magnetization loops (those inside the major loop).

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This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Science Division, of the U.S. Department of Energy under grants DE-FG03-99ER45776, DE-FG06-86ER45275, and DE-AC03-76SF00098.

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